FIELD EXPERIMENTS ON THE DETERIORATION OF SCOTCH POTATO SEED IN ENGLAND

BY

W. BROWN

AND

V. H. BLACKMAN

IMPERIAL MYCOLOGICAL INSTITUTE
1 JAN. 1931

REPRINTED FROM
THE ANNALS OF APPLIED BIOLOGY
VOL. XVII, NO. 1, FEBRUARY, 1930

CAMBRIDGE
AT THE UNIVERSITY PRESS

PRINTED IN GREAT BRITAIN

[From THE ANNALS OF APPLIED BIOLOGY, Vol. XVII, No. 1, February, 1930.]

[*All rights reserved.*]

FIELD EXPERIMENTS ON THE DETERIORATION OF SCOTCH POTATO SEED IN ENGLAND

By W. BROWN and V. H. BLACKMAN.

(*Department of Plant Physiology and Pathology, Imperial College of Science and Technology, London.*)

(With 3 Text-figures.)

Introduction.

The modern view of the deterioration, *i.e.* loss of yielding power, of potato stocks is that it is the result of infection with various types of virus disease (mosaic, leaf-roll, crinkle, streak, etc.). Numerous workers have brought forward evidence in support of this view, but particular mention should be made of the work of Schultz and Folsom in America, of Quanjer and Botjes in Holland, and of Murphy in Ireland. This theory of potato deterioration—both as regards stocks in a particular locality and as regards the total stock of a particular variety—stands in opposition to the older theory in which deterioration is ascribed to purely physiological causes. This physiological deterioration has been supposed to be brought about in various ways. It is suggested that the potato, being essentially a plant of cold climates, exhibits a disordered metabolism when grown under warm conditions, with the result that deterioration ensues. Hence it is necessary to import fresh, more vigorous stock from colder latitudes. A refinement of this theory is that deterioration is due to the over-ripeness of the "seed" of plants grown under warm conditions, with the corollary that it is possible to check the onset of deterioration by the use of early-lifted, *i.e.* immature seed. It is well known in fact that under English conditions, early-lifted seed in many cases gives a heavier yield than does late-lifted seed from the same stock. It should be noted, however, that the greater potency of early-lifted seed is easily explicable on the disease theory of deterioration inasmuch as the early-lifted seed escapes the infection which takes place during the later part of the growing season, and therefore gives a progeny freer from disease than does the late-lifted seed.

The aim of the work to be described in this paper was to carry out a series of carefully controlled weight tests over a period of years, with a

view to furnishing evidence bearing on the nature of potato deterioration. More particularly, it was proposed to examine what effect immaturity of seed (as obtained by early lifting) had on cropping power. It is clear that the ideal arrangement in such a programme would be to grow potatoes free from virus disease—and to keep them free—over a number of years in England under a variety of physiological conditions, and to use material so derived for inter-comparison and for comparison with healthy material newly imported from the North. Such a scheme is, however, very difficult of realisation. Even the best of seed material commercially available is not completely free from virus disease of one kind or another. Nor was it always possible under the conditions of this work to ensure adequate segregation of the experimental plots from highly infected material in the neighbourhood. It is not surprising that virus disease made its appearance, in some cases more prominently than in others. It was impossible, therefore, to study the problem in the clear-cut manner indicated above; nevertheless, even with virus disease present, certain broad conclusions could be drawn, as is shown below.

General plan of experiment.

Seed material.

Seed of high quality was obtained from the north of Scotland (Nairn) and planted in three localities in England, viz. at the Rothamsted Experimental Station, Harpenden, Herts, at the South-eastern Agricultural College, Wye, Kent, and at the Harper-Adams Agricultural College, Newport, Shropshire. Three varieties were grown at each place—Great Scot, Kerr's Pink and King Edward.

The experiment was begun in the spring of 1922 and was planned in the first instance to run for a period of three years. The three-year period was chosen as it is a common practice in English potato-growing districts to use home-grown seed which is at most one year removed from Scotland. General experience is, therefore, that deterioration sets in during the course of the third season's growth.

The procedure was the same for all three varieties and was substantially the same at all three places. It will be sufficient to describe the procedure at one place, *e.g.* that at the Wye College.

A compact plot (about $\frac{1}{3}$ acre) was planted with freshly imported Scotch seed of the three varieties in the spring of 1922. From this plot seed was lifted at three stages of maturity: (1) very early, (2) medium early, and (3) at the normal time. The first lifting was made at about the

time when tubers of normal seed-size (seven to the pound) could be obtained from the young plants. Generally speaking it was not practicable to ensure that all of the very early-lifted seed was of normal seed size, so that the average seed of this type was distinctly small. The medium early seed was lifted about a month later than the preceding, and about two months in advance of the normal lifting. The actual dates for the plots at Wye were:

Date of planting	May 1st
Very early lifting	July 17th
Medium early lifting	August 16th
Normal lifting	October 31st

An additional experiment was designed with a view to testing the effect of reduced insolation on the growing plants. For this purpose a limited number of plants (*circa* 30) of each variety were grown under a screen. The screening material, which was a light white canvas, was supported on the top of a wooden framework, and it was also carried down 9 inches on all sides. Apart from the uppermost 9 inches, the sides and ends of the framework were open. The height of the framework when in position was about 4 feet, so that the growth of the plants was not restricted. The position of the screen was such that the plants beneath it were protected from direct sunlight during the hotter hours of the day. The shaded plants thus grew under conditions of reduced sunlight and with the soil at a lower temperature than usual, *i.e.* conditions which tended to approximate to those obtaining in Scotland. These plants, as might be expected, showed a somewhat drawn appearance and were definitely later in ripening. It is of interest also to record that they were less attacked by blight than were plants of the same variety growing in the open close by. This effect may have been due to the later ripening of the screened plants, or to the latter being protected from dews and light rains. It may also be that the screens to some extent prevented the deposition of spores of the blight fungus. Seed from the screened plants was lifted in all cases at the time of normal lifting.

Thus at the end of the 1922 season the types of seed saved were as follows:

Very early lifted	$= VE_1$
Medium early lifted	$= ME_1$
Lifted at normal time	$= N_1$
Screened (and lifted at normal time)	$= Sr_1$

The suffix indicates that each type had been grown one year in England.

In 1923 a fresh importation of Scotch seed, from the same district in Northern Scotland, was made and planted out alongside the seed types listed above. A certain number of yield tests were made (see later), but the greater part of the material was reserved for seed for the following year. The VE_1 material was again lifted very early, the ME_1 was lifted medium early, and the Sr_1 type was again grown under a screen and lifted at the normal time. The types of seed available at the end of 1923 were therefore as follows: VE_2, ME_2, Sr_2, N_2 and N_1, the last being the produce of the fresh Scotch seed which was imported in the spring of 1923. The suffixes, as before, indicate the number of years that the particular seed had been grown in England.

In 1924 an elaborate weight test was carried out. A further importation of Scotch seed was made as before, so that the full list of types tested was as follows:

S, fresh Scotch seed;

N_1, one year grown in England and lifted at normal time;

N_2, Sr_2, VE_2, ME_2, all grown two years in England and respectively lifted at normal time throughout, screened and lifted at normal time throughout, lifted very early throughout, and lifted medium early throughout.

At Rothamsted and Harper-Adams College, the same plan was adopted with the simplification that at the former place only one early lifting was made, and at the latter the screening experiment was omitted.

Lay-out of field tests.

For weighing purposes, the standard "plot" consisted of twenty plants spaced evenly along 25 feet of a furrow. The plan of the lay-out will be more clearly understood by reference to Fig. 1 which represents a small central portion of the experimental field at Rothamsted in 1924. In this case fourteen furrows were drawn across the field, and along these the various seed types were planted as indicated in the figure. The number of replications is shown below (*v.* Table II). Rows 1 and 14 were planted with Scotch seed and were used simply as guard rows, *i.e.* the produce of these was not weighed. Gaps of about 1 yard were left between each series of plots, as shown by dotted lines in the figure. The first few yards at the ends of the furrows, where greater mechanical injury was likely to take place in the course of cultivation, were planted up with Scotch seed only and were not included in the test.

The various types of seed followed in succession, as shown in the figure. Some of the types, *e.g.* the screened, and to a less extent the

early-lifted, were available only in limited quantity. When these were exhausted, the replication was continued with the remainder. The comparisons are thus more complete for certain types of seed than for others. The number of such plots in 1924 at Wye when the main test was made was 298. The number at Rothamsted and at Harper-Adams College in the same year was of the same order but somewhat less.

Each plot of twenty plants was lifted, cleaned and weighed separately. In this main test, all the plots were lifted at the normal time.

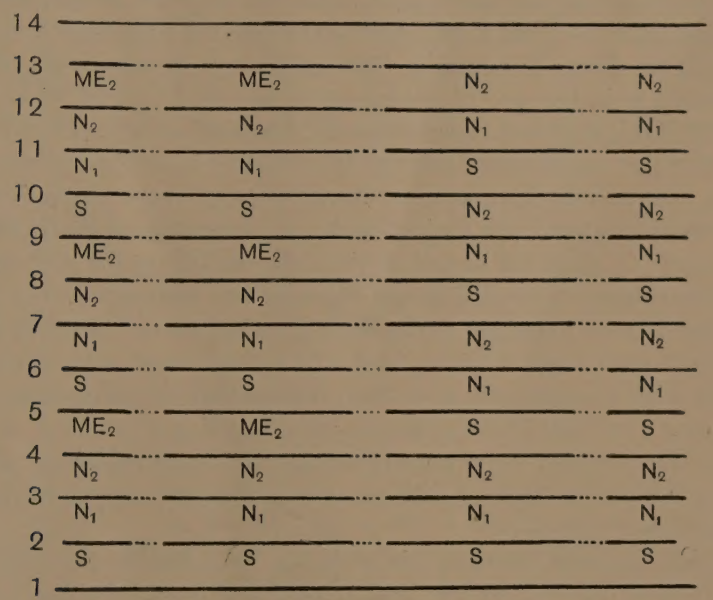

Fig. 1. Figure showing layout of experiment at Rothamsted Experimental Station in 1924; fourteen furrows are shown. S, fresh Scotch seed; N_1, seed grown one year in England and lifted at normal time; N_2, as N_1 but grown two years in England; ME_2, grown two years in England and lifted at a medium early date.

Rogueing. The types of seed which have been described above represent all those which were carried through to the finish of the experiment. To begin with, however, a somewhat wider scope was envisaged, and a test was to be carried out of the effectiveness of a scheme of rogueing in checking the spread of virus diseases over a plot which was liable to infection from diseased material growing in the neighbourhood. For this reason the original mass plots, as planted in 1922, were placed in the neighbourhood of plots containing a high percentage of diseased plants. For example, the plot at Wye was surrounded on three sides by such

highly diseased material. It was proposed therefore to have, in addition to the seed types already mentioned, such further types as (1) seed from the neighbourhood of diseased material, and which had not been rogued, (2) similar seed which had been rogued. It soon became apparent that with the experimental area available, the multiplication of seed types, some of which would be expected to become highly diseased, would defeat the object of the experiment. Accordingly the scheme was soon simplified, but not before a certain amount of otherwise avoidable infection had taken place. The seed that was actually raised in season 1922 was taken from a part as far removed as possible from the surrounding diseased material. The maximum distance was about 20 yards, and in the case of one variety was only 10 yards. It is very doubtful if this degree of isolation can be described as safe. At any rate it is clear that unnecessary risks of deterioration from virus disease infection were run in the first year. In subsequent years contamination from inferior material was avoided as far as circumstances would admit.

In order to check the spread of virus disease among the seed stocks a definite scheme of inspection and rogueing was carried out. The plots were given three rogueings during each growing season, the first when the plants were about 6 inches high, the second about a month later, and the third a month later still. It is obvious that the above cannot be considered a fair test of the effectiveness of rogueing as a means of controlling virus disease. More numerous inspections and rogueings, with a view to eliminating diseased plants as soon as they were apparent, would clearly be more effective.

During the early course of this work, viz. from 1922 to 1924, the aim was to test the effect of various treatments (early lifting, shading) on the yielding capacity of seed. From 1925 to the present date the experiment was continued with a somewhat changed objective, viz. to see how far the yielding power of seed grown in England could be maintained at the standard of Scotch seed by annual rogueing. For the sake of clearness the results obtained in these two tests will be described separately.

Effect of early lifting and shading on the yielding capacity of potato seed.

1. *Rothamsted experiment.*

1922. The plots at this station were planted in the form of a long strip with potatoes along one side and turnips along the other. The seed for the following year was taken from the side of the strip next the turnips.

It is perhaps on account of this original lay-out that virus diseases were more effectively held in check here than at the other two stations.

1923. The seed saved from 1922, viz. N_1, ME_1 and Sr_1, together with fresh S seed, was planted out in the midst of a field of Kerr's Pink potatoes (Scotch seed). The amount of disease shown in the various plots

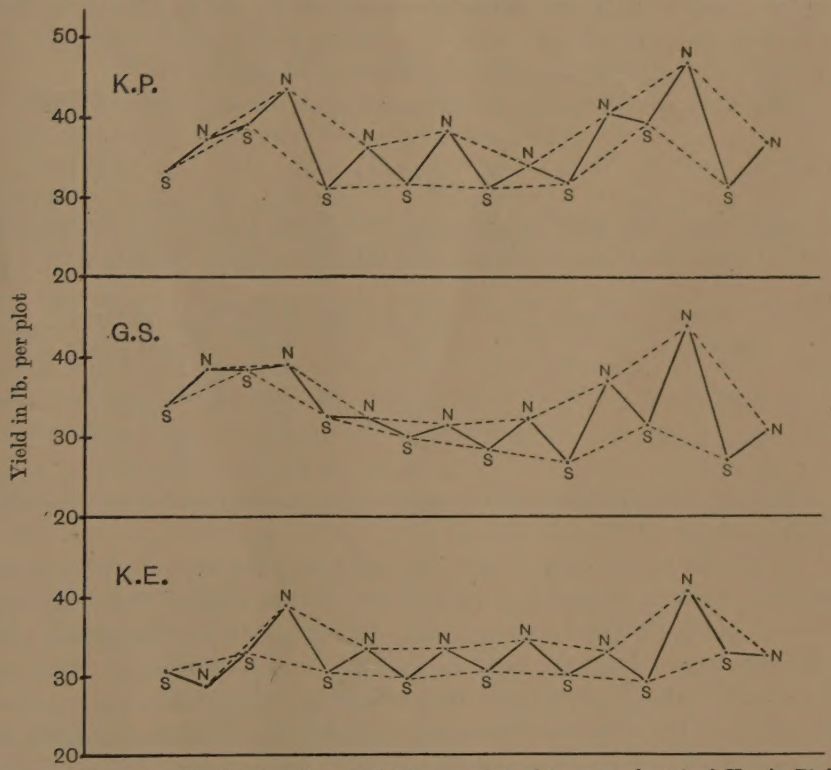

Fig. 2. Three graphs showing the yield (lb. per plot of twenty plants) of Kerr's Pink (K.P.), Great Scot (G.S.) and King Edward (K.E.) at Rothamsted in 1923. For each variety, the yields of eight plots of fresh Scotch seed (S) and of seed grown one year in England and lifted at the normal time (N) are shown; the N and S plots were arranged alternately across the field.

was negligible—viz. out of 2400 plants, three plants showing definite symptoms of leaf-roll were rogued out. These were all present in seed of the N_1 type.

A comparison between S and N_1 seed of the three varieties gave an interesting result. It is commonly stated by potato growers that one-year grown (N_1) seed generally yields a heavier crop than does fresh Scotch seed. Confirmation of this belief is seen in Fig. 2, which represents

the yields (in lb. per plot of twenty plants) of alternating plots of S and N_1 seed of the three varieties. It will be seen that the N_1 plots in nearly every case outweigh the S plots. The result is perhaps most clearly shown by joining up the consecutive S and N_1 points separately, as is done in the figure by the dotted lines. The superiority of the N_1 seed in yielding power over all the S seed is seen inasmuch as the curve joining up the N_1 points lies everywhere above the S curve, with a single exception at the left-hand extremity of the King Edward series.

The statistical data for this comparison are given in Table I below.

Table I.

A comparison of the yielding powers of fresh Scotch (S) and one-year grown (N_1) seed. The mean weight per plot with the probable error is given.

Variety	Type of seed	No. of plots	No. of plants	Av. wt. per plot (lb.)
Great Scot	S	8	157	31·31 ±0·94
„	N_1	8	156	35·88 ±1·12
Kerr's Pink	S	8	160	33·75 ±0·85
„	N_1	8	158	39·44 ±1·02
King Edward	S	8	157	30·81 ±0·33
„	N_1	8	159	34·44 ±0·88

The difference in favour of the one-year grown (N_1) seed is statistically significant for all three varieties.

It should be stated that the N_1 seed had been kept in trays over winter, so that good sprouts were present at the time of planting. The S seed, on the other hand, was only brought south in the spring and planted straight from the bags, so that any sprouts which were present were liable to be damaged or broken off. It is probable that a great deal if not all of the difference observed could be explained on the basis of these different modes of treatment.

The average yield of the forty-eight plots is approximately 34·5 lb. With the spacing adopted this corresponds to a yield of 9·5 tons to the acre, *i.e.* to a good average crop. It may be added that unless in these experiments a good average crop was realised from seed of good quality, no significance was attached to any comparative results that might be obtained.

1924. The types of seed planted were S, N_1, N_2, ME_2 and Sr_2 for each of the three varieties. The fresh Scotch seed (S) was brought down early in the year and sprouted in trays like the remaining types. All the seed was thus well sprouted at the time of planting. The number of plots of each kind is shown in Table II.

Table II.

Showing number of plots of each type of seed (*Rothamsted*, 1924).

Variety	Types of seed				
	S	N_1	N_2	ME_2	Sr_2
Great Scot	24	24	24	8	2
Kerr's Pink	24	24	24	8	2
King Edward	24	18	24	2	2

Neither the ME_2 nor Sr_2 types of seed could be tested as thoroughly as the others on account of lack of sufficient seed.

The amount of virus disease detected in the plots was comparatively small, and especially so in the Great Scot variety, though it was greater than was anticipated from the almost complete freedom from disease of the plants of the previous year. All the available seed was used up in the elaborate weight test series described above, so that when it was decided during the course of the season to carry on the work for some years longer, a certain amount of rogueing was deemed advisable. This was done at the first inspection (June 25th). At the subsequent inspections further infected plants were noted but not removed. The actual number of plants removed is indicated in the various tables below. The correct procedure, of course, would be to rogue the plots from which the following year's seed was to be obtained and to leave unrogued the plots for the current year's weight test. The plan adopted was in the nature of a compromise, and though it was not ideal it will appear that the conclusions to be drawn from the data were not seriously affected.

For convenience of presentation, only two types of virus disease will be noted, viz. leaf-roll (L.R.) and mosaic type (M.T.). The latter term is to be taken as including mosaic, crinkle, streak—in fact all forms of virus disease other than leaf-roll. This grouping is practically necessary as the synonymy of the virus diseases of potato other than leaf-roll is far from settled. A further difficulty in determining the amount of infestation with virus disease is that the symptoms are often so slight or indefinite that it is difficult to say off-hand whether disease is present or not. Cases of this kind are indicated below by a question mark. It is obvious also that many plants showing slight symptoms of disease would be passed as healthy, especially under the conditions of fairly rapid inspection which was all that was practicable in carrying out the work. Accordingly, the figures given in the tables undoubtedly understate the amount of virus disease actually present. On the other hand, they represent fairly the condition of the plots as regards virus disease in its more definite

forms, and it is probably only in such forms that virus disease seriously affects the yielding capacity of the crop.

The relative infestation with virus disease and the yielding capacity of the various types of seed will now be given for each of the three varieties (Tables III to IX).

Great Scot.

The amount and kind of virus disease present in the various plots are given in Table III. The figures in the last column represent roughly the percentages of *definitely* infected plants.

Table III.

Amount and kind of virus disease present in plots of Great Scot.

Type of seed	No. of plants (approx.)	Disease present	% diseased
S	480	0	0
N_1	480	3 L.R. +1 ? L.R. +3 ? M.T.	<1
N_2	480	2 L.R. +1 ? L.R. +2 M.T.	<1
ME_2	160	1 L.R. +2 M.T. +7 ? M.T.	2
Sr_2	40	0	0

The corresponding yields per plot (except for the screened seed) are given in Table IV.

Table IV.

Yields (with probable errors) of four types of Great Scot seed.

Type of seed	No. of plots	No. of plants	Av. wt. per plot (lb.)
S	24	466 (466)	31·15 ±0·53
N_1	24	464 (469)	32·70 ±0·73
N_2	24	456 (460)	30·85 ±0·67
ME_2	8	155 (155)	33·70 ±0·92

The number of plants planted was 480 for the first three types and 160 for the last. The figures in the third column of the above table give the number of plants actually present at lifting time; the figures in brackets give the numbers which would have been present if a certain amount of rogueing had not been carried out. None of the average weights as given in the fourth column differs from any other by an amount which is statistically significant. If a correction is made for the plants rogued out, either by allowing for them the average weight per plant, or what would perhaps be fairer, by allowing half the average weight, the conclusion is unaltered, viz. that there is no significant difference in the average yields of the four types of seed. Furthermore, there is no sug-

gestion in the figures that any of the three types of English-grown seed is yielding less than the Scotch seed.

The plots of screened (Sr_2) seed[1] were too few to allow of statistical treatment of the results, but the following figures show that the screened seed gave a yield practically the same as the N_2 seed growing alongside.

Sr_2 (2 plots). Av. wt. = 29·3 lb.
N_2 (2 plots). ,, = 28·6 ,,

Kerr's Pink.

The prevalence of virus disease was distinctly greater than was the case with the preceding variety. Table V gives a record of the amount and type of disease present.

Table V.

Amount and kind of virus disease present in plots of Kerr's Pink.

Type of seed	No. of plants (approx.)	Diseased plants	% diseased plants
S	480	1 M.T. +1 ? M.T.	0–1
N_1	480	1 L.R. +3 ? L.R. +22 M.T. +2 ? M.T.	5
N_2	480	6 L.R. +16 M.T. +2 ? M.T.	5
ME_2	160	8 M.T.	5
Sr_2	40	1 M.T.	2–3

The corresponding yields per plot (except for the screened seed) are given in Table VI.

Table VI.

Yields (with probable errors) of four types of Kerr's Pink seed.

Type of seed	No. of plots	No. of plants	Av. wt. per plot (lb.)
S	24	469	37·23 ±0·64
N_1	24	452	32·82 ±0·55
N_2	24	441	34·54 ±0·59
ME_2	8	158	37·90 ±1·30

In this case both the N_1 and N_2 types show a significant falling off in yield compared with the S type. An appreciable number of plants were, however, rogued out in this series, and some allowance should be made for them. On the basis of an allowance of half the average weight per plant for those which were rogued out, the figures are as in Table VII.

As now calculated, the yield of the N_1 type of seed is significantly less than that of the Scotch seed, whereas that of the N_2 is no longer so. Even when full average weight is allowed for the plants rogued out, the difference between the yields of S and N_1 seed is significant.

[1] It is to be noted that this stock was grown under the screen in seasons 1922 and 1923, but that it was planted in the open, side by side with the other types of seed, in 1924.

Table VII.

Corrected yields for four types of Kerr's Pink seed.

Type of seed	No. of plots	No. of plants (corrected)	Av. wt. per plot (lb.)
S	24	471	37·30 ±0·62
N_1	24	467	33·36 ±0·54
N_2	24	459	35·27 ±0·60
ME_2	8	158	37·90 ±1·30

The figures given in Tables VI and VII indicate a falling off of the N_1 and N_2 types as compared with fresh Scotch seed, though on the data available this deterioration is only statistically significant for the N_1 type of seed. That the N_1 type should apparently deteriorate more than the N_2 type is remarkable, but it is not clear what meaning is to be attached to the apparent difference. It is noteworthy also that the ME_2 type of seed shows no evidence of deterioration even though it contains more or less the same percentage of diseased plants as the N_1 and N_2 types.

The comparison of the screened (Sr_2) seed with the corresponding normal (N_2) seed growing alongside gave the following figures:

Sr_2 (2 plots). Av. wt. = 28·0 lb.
N_2 (2 plots). ,, = 33·3 lb.

The number of plots is too small to allow of the significance of these figures being estimated, but at any rate there is no indication that the protection from high temperatures afforded to the plants in the preceding years has in any way increased their yielding power.

King Edward.

The percentage of plants showing virus disease was fairly similar to that shown by the Kerr's Pink plots. The record of diseased plants is given in Table VIII.

Table VIII.

Amount and kind of virus disease present in plots of King Edward.

Type of seed	No. of plants (approx.)	Diseased plants	% diseased plants
S	480	1 ? M.T.	0
N_1	360	1 L.R. + 16 M.T. + 2 ? M.T.	5
N_2	480	5 L.R. + 23 M.T. + 13 ? M.T.	6
ME_2	40	1 M.T.	2–3
Sr_2	40	2 M.T.	5

The yields of the three types of seed, S, N_1 and N_2, were determined over a series of eighteen plot replications. The results are given in Table IX.

Table IX.

Yields (with probable errors) of three types of King Edward seed.

Type of seed	No. of plots	No. of plants	Av. wt. per plot (lb.)
S	18	349	29·22 ±0·42
N_1	18	351	27·83 ±0·48
N_2	18	323	27·53 ±0·72

Both the English-grown types of seed show a falling off in yield as compared with the Scotch, but in neither case is the drop statistically significant. The yield of the N_2 type is unduly low on account of a somewhat poor stand of plants (from causes unknown) and it is not clear that there is in this case any falling off in yield significant or otherwise. In spite, therefore, of a certain percentage (*circa* 5 per cent.) of virus-infected plants among the English-grown King Edward plants, there is no clear evidence of any deterioration in yielding power.

Only two plots each of the early-lifted (ME_2) and screened (Sr_2) types of seed were available for comparison. The results for these and for the two rows of N_2 seed growing alongside were as follows:

N_2 (2 plots). Av. wt. = 28·0 lb.
ME_2 (2 plots). „ = 30·8 lb.
Sr_2 (2 plots). „ = 24·5 lb.

The duplicate plots were not in good agreement so that the significance of these figures is doubtful. As regards the screened seed, however, the figures do not indicate any difference from the behaviour of the other two varieties.

2. *Wye experiment.*

1922. That the plots at Wye in 1922 were exposed to considerable risk of infection has already been stated (p. 6); this is in all probability one of the reasons why the plots at this centre have shown in subsequent years a greater degree of infection with virus disease than the corresponding plots at Rothamsted. The types of seed lifted were the same as at the latter centre, with the addition of a very early type (VE).

1923. The proportion of leaf-rolled plants present in the plots, especially in those of King Edward, was in marked contrast with that shown at Rothamsted. Table X shows the data for the plots of Great Scot and King Edward.

The presence of 3 per cent. of leaf-rolled plants in the plot of Scotch King Edward was very exceptional, the general experience in this work being that the seed from Banffshire was of very high quality.

Table X.

Percentage of leaf-rolled plants in plots of Great Scot and King Edward.

Type of seed	Great Scot	King Edward
S	0·3	3
N_1	2	7
VE_1	2	2
ME_1	1·5	0·6
Sr_1	1	3

The plots of Kerr's Pink were practically free of leaf-roll, there being only two diseased plants in the whole series of plots of this variety.

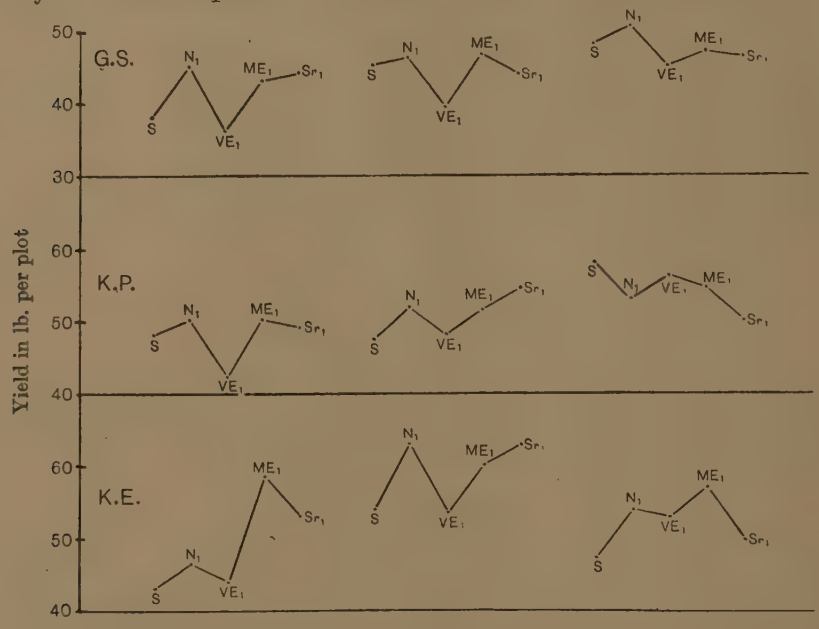

Fig. 3. Graphs showing yields of Great Scot, Kerr's Pink, and King Edward potatoes in 1923 at Wye. S and N, as in Fig. 2; VE_1, seed lifted very early and grown one year in England; ME_1, seed lifted medium early and grown one year in England; Sr_1, seed from screened plants grown one year in England.

An unfortunate circumstance in the history of these plots was that there was considerable intermixture with self-sown rogues over a certain area of the plots. Care was always taken in this work that the potatoes did not succeed a potato crop of the preceding year, but in this instance the presence of rogues was found to be due to potato fragments among the farmyard manure used. Practically all these rogue plants (fifty-two altogether) showed some form or other of virus disease. They were

removed at the first inspection (June 22nd). At this date only few aphides were observed, but nevertheless it is not improbable that some infection had already taken place.

As the majority of the material was reserved for seed for the following year only a limited number of weight tests was carried out. The data are too few to warrant statistical treatment, but certain conclusions are indicated, as may be seen from Fig. 3. If we consider the three varieties together, it is seen that out of nine comparisons between S and N_1 plots, the yield of the latter exceeds that of the former in eight cases. This is a further indication of the rule found to apply at Rothamsted, that the one-year grown seed yields somewhat more heavily than fresh Scotch seed. A second feature, also shown in eight cases out of nine, is the dip in the curves at the point corresponding to the very early lifted (VE_1) type of seed. Though this is the only occasion on which this effect has been observed, the agreement among the curves indicates that very early lifted seed may be inferior to late-lifted seed, even though it may contain a smaller percentage of diseased plants (see figures for King Edward variety in Table X). The very early lifted seed in this case was lifted on July 17th and was thus very immature. The result of this test so far as it goes thus supports the view of Murphy and McKay[1], which is that very immature seed, in the absence of virus disease, is intrinsically inferior to seed lifted at the normal time.

1924. On account of the considerable infestation with virus disease which became obvious during the growing season, the weight test plots were not rogued, but a number of plots, which had originally been laid out for weighing, were severely rogued and used solely for the supply of seed for the following year.

In the Great Scot variety, about 5 per cent. of leaf-rolled plants were present in the plots of one- and two-year English-grown material. The other two varieties showed somewhat more, up to 10 per cent. in some plots. The commonest type of virus disease was, however, of the mosaic type, viz. a kind of streak[2]. This disease was undoubtedly present in a mild form in the preceding year, but had now become much more widely spread and produced more distinct symptoms on the attacked plants.

[1] Murphy, P. A. and McKay, R., "Investigations on the Leaf Roll and Mosaic Diseases of the Potato." *Journ. of Dept. of Lands and Agric., Irish Free State,* xxv, No. 2, 18.

[2] The type of streak is that known as "leaf-drop" streak. It is not the "stipple streak" of Atanosoff (*Meded. Landbouwhoogeschool, Wageningen,* xxiv, No. 5, p. 32, 1922). The affected plants do not succumb to the disease in the manner characteristic of "stipple streak." "Leaf-drop" streak and its relation to other virus diseases, such as mosaic and crinkle, are far from clear. Compare footnote on p. 20.

The general effect of this disease being to cause the premature death of the haulms, a rough idea of its prevalence was obtainable by counting towards the end of the season the number of prematurely ripened plants. A sample set of figures, obtained in this way, is shown in Table XI.

Table XI.

Percentage of fully ripened plants on September 9th.

Seed type	% of ripened plants	
	Great Scot	Kerr's Pink
S	1	2
N_1	40	54
N_2	32	44
VE_2	11	47
ME_2	25	68
Sr_2	30	55

It is not certain that all the faded plants were infected with virus disease, though undoubtedly most of them were so. Table XI clearly shows how all the English types of seed showed up badly in this respect when compared with the fresh Scotch seed. A general review of all the plots of all the varieties showed that the VE_2 type of seed was certainly less infected than any of the other English-grown types, but the difference was not always clearly marked.

The results of the weight tests are given in Tables XII, XIV and XV below.

Table XII.

Yields (with probable errors) of six types of Great Scot seed.

Seed type	No. of plots	No. of plants	Av. wt. per plot (lb.)
S	11	216	$41{\cdot}8 \pm 1{\cdot}40$
N_1	11	205	$31{\cdot}5 \pm 1{\cdot}10$
N_2	11	201	$29{\cdot}0 \pm 0{\cdot}97$
VE_2	10	199	$38{\cdot}8 \pm 1{\cdot}59$
ME_2	10	197	$32{\cdot}7 \pm 1{\cdot}38$
Sr_2	6	113	$31{\cdot}7 \pm 1{\cdot}18$

Calculation from the data of Table XII shows that definite deterioration has taken place in the N_1, N_2, ME_2 and Sr_2 types of seed as compared with that fresh from Scotland. The yield of the VE_2 type of seed is also less than that of the Scotch, but the difference is not significant. On the other hand, the yield of the VE_2 seed is significantly greater than that of the N_2 type, thus proving in this case the advantage derived from early lifting.

An examination of the figures in the third column of Table XII and of Tables XIV and XV below shows that the number of plants present at harvesting time relative to the number planted is less for the seed types N_1, N_2 and Sr_2 than for the other three types[1]. The data are brought together in Table XIII.

Table XIII.

Percentage "germination" of different seed types.

Seed type	Great Scot	Kerr's Pink	King Edward
S	98·2	98·0	100
N_1	93·2	90·9	91·8
N_2	91·4	90·0	88·6
VE_2	99·5	98·3	99·5
ME_2	98·5	98·9	97·3
Sr_2	94·1	88·8	80·0

The cause of the higher percentage of "misses" among the late-lifted English types was probably the presence of the potato blight fungus on the sets. When a correction is made for this irregularity of sprouting by giving full value to the missing plants, the conclusions derived from Table XII above and Tables XIV and XV below are unaffected.

Kerr's Pink.

Table XIV.

Yields (with probable errors) of six types of Kerr's Pink seed.

Seed type	No. of plots	No. of plants	Av. wt. per plot (lb.
S	12	235	$41·2 \pm 1·22$
N_1	11	200	$30·0 \pm 0·99$
N_2	11	197	$29·7 \pm 1·16$
VE_2	9	177	$34·1 \pm 1·38$
ME_2	9	178	$30·8 \pm 1·54$
Sr_2	8	142	$29·0 \pm 1·78$

Compared with the fresh Scotch seed, all the types of English-grown seed have definitely deteriorated. The VE_2 type, though better than the corresponding late-lifted (N_2) type, is not significantly so. The types N_1, N_2, ME_2 and Sr_2 show negligible differences. The general result is thus similar to that shown by the Great Scot series, except that deterioration is somewhat more pronounced. Thus, in contrast with the results for the first

[1] The number of plants planted is obtained by multiplying the number of plots as given in column 2 by 20.

variety, the VE_2 type of seed shows definite deterioration as compared with Scotch seed, and is not significantly different from late-lifted seed (N_2) which has been grown for the same period of time in England.

King Edward.

Table XV.

Yields (with probable errors) of six types of King Edward seed.

Seed type	No. of plots	No. of plants	Av. wt. per plot (lb.)
S	12	240	32·7 ± 1·34
N_1	11	202	24·4 ± 1·11
N_2	11	195	19·0 ± 1·15
VE_2	11	219	28·5 ± 1·78
ME_2	11	214	24·3 ± 1·24
Sr_2	4	64	24·0 ± 0·42

Compared with Scotch seed, all the English types except VE_2 show significant deterioration. The VE_2 type is not significantly different from the S type, but is significantly greater than the N_2 type. The results are thus similar to those obtained for the variety Great Scot.

In carrying out the above weight tests at Wye in the season 1924, certain observations were made which in themselves indicate whether virus disease or the direct influence of climate is responsible for loss of cropping power. If deterioration were due to climatic influence *per se* one would expect to find evidence of some general physiological change more or less uniformly marked in all the plants which had been under the same conditions. Thus the deteriorated N_2 plots would be expected to show some fairly uniform reduction in size of the haulms. This general reduction in haulm would then be associated with a general tendency to poor yield in each plant. This, however, is not the case. The plots which gave poor yields did so, not because each plant was slightly deteriorated, but because the plots were composed of a mixture of normal plants giving normal yields and highly deteriorated plants giving very small yields. The discontinuous nature of the degeneration effect obviously does not fit in with the physiological theory of deterioration, while it is just what would be expected on the disease theory.

The feature just referred to is well brought out in Table XVI, which is based on separate weighings of the healthy and diseased plants in a number of deteriorated plots of the Kerr's Pink variety. The plants which showed no symptoms of virus disease in their haulms and those which did were marked, and at lifting time the two lots were weighed separately.

Table XVI.

Average yield per root of healthy and diseased plants of Kerr's Pink.

Type of seed	Plants in plot	Healthy	Av. wt. (lb.)	Diseased	Av. wt. (lb.)
N_1	19	14	1·96	5	1·05
N_1	19	14	2·32	5	1·05
N_1	15	8	2·25	7	0·90
N_2	16	11	2·50	5	1·20
N_2	20	13	2·54	7	0·36
ME_2	20	11	2·00	9	0·72
ME_2	20	11	2·32	9	1·10

The average weight per root for the diseased plants is 0·91 lb. as against 2·27 lb. for the healthy. The latter figure is fully equal to that of the Scotch plots of this variety.

Harper-Adams experiment.

The experiment at Harper-Adams College for the period 1922–4 ran a course fairly similar to that described for the experiment at Wye. A good deal of disease appeared, partly on account of risks which were run in the first year, and partly because the programme of rogueing could not be adhered to satisfactorily. The records of the various plots in season 1923 are very similar to those already given for the Wye experiment, and as the main weight test laid out in 1924 proved to be an utter failure, it is unnecessary to reproduce the details. In season 1924 the experimental field suffered from a heavy flooding in middle summer and the whole crop was ruined. Weighings were carried out in the autumn as usual, but so poor was the crop that even the plots from fresh Scotch seed only yielded at the rate of 1 to 2 tons per acre. The weighings were therefore quite valueless.

Continuation of the experiment.

From 1925 onward the work was continued in a simplified form and, as has already been mentioned, with a somewhat changed objective. By the end of 1924 all the stocks had in greater or less degree become infected with virus disease. The experiment was therefore continued with the object of seeing how far rogueing was effective in eliminating disease, or failing elimination, in preventing further deterioration. Only the late-lifted seed (excluding screened) was carried on at each place. Further simplifications were introduced later, *e.g.* discontinuing the experiment at Harper-Adams College in 1927 and dropping the King Edward variety on account of certain difficulties in rogueing. It will be sufficient there-

fore for the present purpose to limit the account so as to deal only with the results obtained for the Great Scot and Kerr's Pink varieties at Rothamsted and Wye.

Rothamsted.

1925. The seed of Great Scot saved from the previous year was unfortunately lost through the depredations of rats, so that only fresh Scotch seed of this variety was planted in 1925. The types of Kerr's Pink seed planted were S, N_1, N_2, and N_3, the notation being as before. In addition to the plots which were rogued and which were reserved for seed for the following year, a twelve-fold replication of plots for weighing was laid out for the Kerr's Pink variety. The percentage of diseased plants and the yields for the various seed types are given in Table XVII.

Table XVII.

Giving percentage of virus disease present and yields per plot for four types of Kerr's Pink seed.

Seed type	No. of plots	No. of plants	% diseased	Av. wt. per plot (lb.)
S	12	238	0·4	32·3 ±1·03
N_1	12	231	3	31·3 ±1·01
N_2	12	233	14	27·0 ±0·89
N_3	12	232	12	29·8 ±0·94

In this series, deterioration is definite only in the case of the N_2 stock. It is also indicated in the N_3 stock but it has not reached significant dimensions. The general correlation of fall in yield with prevalence of virus disease is well shown in the above table.

1926. The only seed types carried on were N_1 for Great Scot and N_4 (*i.e.* the progeny of N_3) for Kerr's Pink. No weight tests were attempted, but a small lot of seed was planted, with a spacing of 2 yards, in a single row in a turnip field. No obvious disease of any sort appeared in the one-year grown Great Scot seed. With the four-year grown Kerr's Pink, virus disease of the streak type[1] was shown in the course of the season in fully 50 per cent. of the plants. No diseased plants were removed, but the course of the disease was observed by fortnightly inspections throughout the growing season. In the following year seed was taken only from those plants which showed no signs of virus disease right up to the end of the growing period. The produce of the individual plants was weighed, giving the following average yields:

[1] The relative prominence of necrotic spotting and streaking on the veins, of corrugation and mottling of the leaflets varied greatly from plant to plant, as detailed fortnightly inspections showed, so that it is probable that a very mixed type of infection was present.

Healthy. 22 plants. Av. yield per plant, 4·20 lb.

Diseased (in some cases only very slightly). 25 plants. Av. yield per plant, 2·41 lb.

1927. Again no weight tests were attempted, but two rows of plants of the two varieties (N_2 seed of Great Scot and N_5 of Kerr's Pink) were grown with swedes along one side and with fresh Scotch seed along the other. The plants were spaced at 1 yard intervals along the rows.

No definite symptoms of disease appeared in the Great Scot plants. On the other hand, the plants of Kerr's Pink, though derived from those which appeared quite free from disease in the preceding year, contained a high percentage of infected plants. Some of the latter only showed faint symptoms, but nevertheless all plants showing symptoms of disease, however slight, were rogued out early in the season (seven weeks after the date of planting). The plants so rogued out constituted 64 per cent. of the whole crop. Seed was collected from the remainder at the end of the season.

1928. A weight-test series was laid out in which a comparison was made between fresh Scotch seed and three-year grown English seed for the Great Scot variety, and between fresh Scotch seed and six-year grown English seed for the Kerr's Pink variety. During the growing season the amount of virus disease present was as follows: slightly less than 4 per cent. (mosaic type only) in Kerr's Pink and 4 to 5 per cent. (chiefly leaf-roll) in Great Scot.

The yields are given in Table XVIII.

Table XVIII.

Yields (with probable errors) of two types of seed of Great Scot and Kerr's Pink varieties.

Variety	Seed type	No. of plots	No. of plants	Av. wt. per plot (lb.)
Great Scot	S	16	300	28·2 ± 0·63
,,	N_3	16	298	27·5 ± 0·47
Kerr's Pink	S	14	263	26·7 ± 0·77
,,	N_6	14	258	32·2 ± 0·68

The difference between the yields of the two types of Great Scot seed is negligible. On the other hand, the yield of the English-grown Kerr's Pink seed is significantly greater than that of the Scotch seed.

That the English-grown seed of Kerr's Pink yielded more heavily than fresh Scotch seed is probably to be explained, as suggested earlier (p. 8), by the fact that the former were, from the conditions of the experiment, better sprouted at the time of planting. In any case it is clear that the

English-grown seed, after the drastic and apparently successful rogueing of the year before, has yielded fully as heavily as freshly imported Scotch seed.

Wye.

1925. In addition to plots for seed production for the following year, a series of weight-test plots was laid out with the following seed types—S, N_1, N_2 and N_3—for both Great Scot and Kerr's Pink varieties. No exact determination of the percentage of virus disease present could be made as the plots, which were on newly broken up famished grass land, grew poorly and showed obvious symptoms of potato hunger. The effects of the latter are not easily distinguished from certain types of virus disease. There was no doubt, however, that considerable virus disease was present, especially in the N_2 and N_3 plots. The weighings showed that the two types of seed just mentioned were definitely deteriorated, whereas the N_1 type yielded much the same as the fresh Scotch seed. The general crop yield was poor, for the reason stated, being at the rate of about 3 to 4 tons per acre, so that the comparisons obtained are of little value.

1926 and 1927. In both of these years the procedure was much the same as at Rothamsted—*i.e.* the oldest stocks (N_3 of season 1925) were carried on, with rogueing, for two years longer. The percentages of diseased plants removed were 6 and 10 per cent. in 1926 and 0 and 30 per cent. in 1927 for Great Scot and Kerr's Pink respectively. The rogueing was not carried out so drastically as at Rothamsted, and a number of plants which probably showed slight symptoms of disease were allowed to remain in the case of both varieties.

1928. A weight-test series was laid out in which fresh Scotch seed and six-year grown English seed (N_6) were compared for both varieties. The extent of the test was limited owing to the fact that some of the seed was killed by the severe frost of December 1927. During the growing season the prevalence of virus disease was found to be 10 per cent.

Table XIX.

Yields (with probable errors) of two types of seed of Great Scot and Kerr's Pink varieties.

Variety	Seed type	No. of plots	No. of plants	Av. wt. per plot (lb.)
Great Scot	S	4	80	33·6 ±0·35
,,	N_6	4	80	33·0 ±0·96
Kerr's Pink	S	4	80	29·4 ±0·6
,,	N_6	4	80	28·8 ±0·3

(nearly all leaf-roll) in Great Scot, and 28 per cent. (streak, slight in the majority of cases) in Kerr's Pink. The yields are given in Table XIX.

From this table it is seen that a slight drop in yield is shown by the English-grown seed of both varieties, but in both cases it is not significant in amount. This result may appear surprising, especially with the Kerr's Pink variety, the English-grown plots of which had a considerable percentage of virus disease, but it is to be noted that the great majority of the affected plants only showed incipient symptoms of disease, so that the actual effect on yield in the current year was negligible.

Discussion of results.

The results set out in the foregoing are best considered in two sections, referring to the periods 1922–4 and 1925–8 respectively. The work of the former period will be dealt with first.

It is clear from a study of the data presented in the various tables that there is a general parallelism between the amount of virus disease showing in any plot and the yield of that plot. Thus in the experiment at Rothamsted in 1924 there was comparatively little virus disease showing and relatively little evidence of deterioration in yielding power. On the other hand, at Wye the incidence of virus disease was much greater and there was a more striking deterioration of the English-grown stocks. This is well shown by the following comparison. Out of fifteen types of English-grown seed at Wye, thirteen showed definite deterioration. At Rothamsted, out of eight types of English-grown seed for which statistical treatment of the results could be attempted, definite deterioration was found in one case only. Then again, at each place differences in degree of attack and of deterioration appeared as among the three potato varieties used. Thus at Rothamsted the plots of Great Scot showed very slight infection with virus disease (at most 2 per cent.), and the results obtained from the weight test gave no suggestion of deterioration. The Kerr's Pink and King Edward varieties, on the other hand, showed a greater prevalence of virus disease and at the same time definite indications of deterioration, though only in one case was the fall in yield of the English-grown seed types statistically significant.

With regard to the screening experiment, the most important results were those obtained at Wye. From these it appeared that the screened plots had deteriorated to a degree quite comparable with the plots of English-grown seed grown in the open in the normal manner. There was no indication that protection of the plants from high temperatures had in any way helped them to maintain their cropping vigour. The similar

experiment at Rothamsted, though conducted on too small a scale to allow of statistical treatment of the results, nevertheless gave no colour to the suggestion that shading of potato plants had any effect on the cropping power of the resultant tubers.

The general conclusions to be drawn from the comparisons between the cropping power of early-lifted and late-lifted seed are fairly clear, and are in agreement with the view which is generally accepted nowadays and which has been put forward, for example, by Murphy and McKay (*l.c.*) and by Botjes[1]. In the experiments at Wye in 1924 the early-lifted seed definitely yielded more heavily than material of similar age in England which was lifted late. This is an illustration of the case where early lifting in the presence of a fair amount of infection with virus disease confers a distinct advantage. Nevertheless, it should be noted that it was only the *very* early-lifted seed which gave this result in a definite manner. It would seem that, in order to obtain a benefit from early lifting when virus disease is present, it might be necessary to lift so early that any advantage would be obliterated by the small yield of tubers available as seed. Again, the plots from very early-lifted seed themselves show definite indications of deterioration when compared with those from fresh Scotch seed, so that it is clear that even very early lifting, while it may retard the onset of deterioration, will not prevent it when virus disease has begun to spread to an appreciable extent.

In the corresponding tests at Rothamsted, data on the effect of early lifting which can be treated statistically are available for the two varieties Great Scot and Kerr's Pink. Very little virus disease was present in the plots of Great Scot, and all these, whether derived from early-lifted, late-lifted or Scotch seed, showed no significant differences in average yield. In fact several of the English-grown types of seed yielded more heavily than the fresh Scotch seed. For Kerr's Pink, which showed a greater prevalence of virus disease, the early-lifted seed gave a heavier yield than the late-lifted, and was fully equal to fresh Scotch seed. The condition of the plots of Kerr's Pink as regards the progress of deterioration is thus seen to be intermediate between that of the Great Scot plots at Rothamsted and the plots of all three varieties at Wye.

The general parallelism between the amount of virus disease shown and the diminution in cropping power does not appear to hold entirely in some cases. For example, in Tables V and VI it is seen that the early-lifted seed yields more heavily than the late-lifted, with no corresponding differences in the percentages of diseased plants. It is to be remembered,

[1] *Report Internat. Conf. Phytopath. and Econ. Entom., Holland*, 1923, p. 146.

however, that the data of percentage of disease present are of necessity somewhat rough, inasmuch as a mere numerical count does not represent adequately the *quantitative* effect of disease on the growth of the plant. An exact correspondence would not therefore be expected.

On the question as to whether a certain degree of immaturity in the seed may confer some advantage, even in the absence of virus disease, the above experiments give no clear indication. The data given in Tables IV and VI might be interpreted as suggesting that the beneficial effect of early lifting cannot be entirely explained on the disease theory. In one case (Table IV) the beneficial effect is very slight, in the other (Table VI) it may be largely explained in the manner indicated in the preceding paragraph. If such an effect really exists, it seems clear that it is inconsiderable, and that very careful experimentation, with virus disease excluded, would be necessary for its demonstration. It is evident, therefore, that while a purely physiological effect on yield due to early lifting has not been disproved by these experiments, it must, if it exists at all, be very small and quite subsidiary to the effects of virus disease.

The experiments of the second period (1925–8) show that, by a course of rather drastic rogueing, it is possible to maintain seed which, after six years' growth in England, gives a yield as good as that of freshly imported Scotch seed. This is a further argument against the physiological theory of deterioration. While thus it has been demonstrated that the vigour of Scotch seed when grown in England can be maintained by rogueing, it does not follow that the method is economically practicable. Very drastic, uneconomic rogueing was necessary in some cases. On the other hand, such excessive rogueing might not have been required in the later years of the test if better facilities had been available throughout, and especially in the earlier years, for the removal of the diseased plants on the first appearance of disease symptoms. The experiment was thus not a fair test of the practicability of rogueing. At the same time, even with the severe rogueing adopted, there is no anticipation that virus disease has been eliminated from any of the seed lots. There are indications that leaf-roll has been eliminated in one case, but it is certain that, short of a process of very rigorous segregation and selection, the elimination of the streak type of disease is impossible. The restoration in this way of the cropping power of a more or less infected stock of potatoes in England shows little likelihood of success as a practical proposition. A more practical line to follow would be to determine whether, by an amount of rogueing which a farmer could be expected to carry out, the life in

England of Scotch seed of good quality could be prolonged from the two to three years which is usual, to say five or six years.

Summary.

1. An experiment with three varieties of potatoes (Great Scot, Kerr's Pink and King Edward) was carried out during the period 1922–24 in order to test the physiological theory of potato deterioration by determining whether the cropping power was influenced by early lifting or affected by shading the growing plants and so protecting them from overheating. The main results of this experiment were as follows:

(*a*) In the absence or very limited presence of virus disease, neither early lifting nor shading produced any significant effect on crop yield. All the types of seed (one-year grown, two-year grown, early-lifted, etc.) gave yields which were not significantly different from that of fresh Scotch seed.

(*b*) When considerable infestation with virus disease was shown, all the types of English-grown seed showed a significant falling off in yield as compared with Scotch seed. In such cases the falling off in yield was not so great with seed which had been lifted at a very early date. Thus, with virus disease present, an advantage may be gained by early lifting of the seed.

(*c*) In one case, evidence was obtained that very immature seed is intrinsically inferior in cropping power to seed lifted at the normal time, *i.e.* apart from the effects due to the unequal distribution of virus disease.

(*d*) In two cases the greater cropping power of one-year grown English seed as compared with fresh Scotch seed was demonstrated. This difference is probably to be explained on the ground of the unequal sprouting at the time of planting.

(*e*) A general correlation was observable between the amount of virus disease present in the various plots and the falling off in cropping vigour.

(*f*) No effect of a purely physiological nature arising from early lifting or from shading was indicated. Though such an effect could not be disproved, it was clear that it was of minor account and quite subsidiary to the effects of virus disease.

2. An experiment was carried out over the period 1925–8 to determine whether, by a process of rogueing, the cropping vigour of a deteriorated stock could be restored. The weight tests carried out in 1928 showed that certain English-grown stocks, some of which were in their seventh year from Scotland, yielded as heavily as Scotch seed.

3. The experiments were carried out in such a way that the statistical significance of the data obtained could be assessed. In thirty-three such experiments, where the yield of English-grown types of seed was compared with that of Scotch seed, the percentage drop in cropping power which was significant varied from 7·0 to 20·0. Over the whole series, the average figure was 11·8 per cent., corresponding to a falling off in yield of about 1·2 tons per acre.

In conclusion we wish to record our thanks, for facilities offered for this work, to the Director of the Rothamsted Experimental Station and to the Principal of the South-Eastern Agricultural College, Wye, and the Principal of the Harper-Adams Agricultural College, Newport, Salop.

(*Received June 13th*, 1929.)